# Circular Polarization and Polarization Losses

*by Rastislav Galuscak - OM6AA, Pavel Hazdra[(1)],*

*[(1)]CTU Prague, FEE, Dept. of Electromagnetic Field, Technicka 2, 166 27, Prague, Czech Republic, E-mail:, om6aa@yahoo.com, hazdrap@fel.cvut.cz*

## Introduction

Circularly polarized microwave radiation is frequently used in EME (Earth-Moon-Earth) communication on the 23, 13 and 6 cm bands. Recently published findings [1] suggest that favorable properties of CP (circular polarization) should also enable utilization on the 3cm band. The main advantage of CP versus linear polarization is that CP eliminates polarization mismatch losses caused by Faraday's rotation and varies the squint angle of polarization vectors between stations on the Earth. This article is intended to familiarize and clarify the application of CP in conjunction with parabolic reflector antennas and to publicize problems that CP antenna designers may encounter.

## 1. Polarization Losses

### 1.1 Definitions

The **polarization** of an electromagnetic wave is defined as the orientation of its electric field vector. If the vector appears to rotate with time, then the wave is elliptically polarized. The ellipse so described may vary in ellipticity from a circle to a straight line, or from circular to linear polarization. So, in the general sense, all polarization may be considered to be elliptical.

**Axial ratio** is the ratio of the major axis to the minor axis of the polarization ellipse:

*as a ratio* *expressed in dB*

$$\text{Axial ratio} = \frac{\text{major axis (Emax)}}{\text{minor axis (Emin)}} \quad \textbf{or} \quad = 20 \log [\text{Emax/Emin}] \qquad (1)$$

**Directivity** is a measure of the concentration of radiation in the direction of the maximum and is easily estimated from the radiation pattern:

*as a ratio* *expressed in dB*

$$\text{Directivity} = \frac{\text{maximum radiation intensit (Umax)}}{\text{average radiation intensity (Uo)}} \quad \textbf{or} \quad = 10 \log [\text{Umax/Uo}] \qquad (2)$$

Gain, on the other hand, must be measured and is related to directivity by an efficiency factor:

*as a ratio* *expressed in dB*

Gain = directivity (***ratio***) **x** efficiency **or** = 10 log[directivity (***ratio***) **x** efficiency] (3)

Analysis of circular polarization (CP) utilizes two independent, orthogonal, components: right- and left-hand circular (RHC and LHC). The desirable component, having the intended sence of rotation (right, or left), is called the **copolarization** component. The undesirable component, with the opposite polarization, is called the **crosspolarization** component. The mix of copolarization and crosspolarization components determine the quality of CP and correlates with the axial ratio. More details can be found in [2].
If incident radiation is polarized differently from that which an antenna is designed to receive, then the power available at the antenna output will be less than maximum. This loss resulting from polarization mismatch can vary between infinity and zero. To better analyze this problem, we can divide it into two interfuse groups:

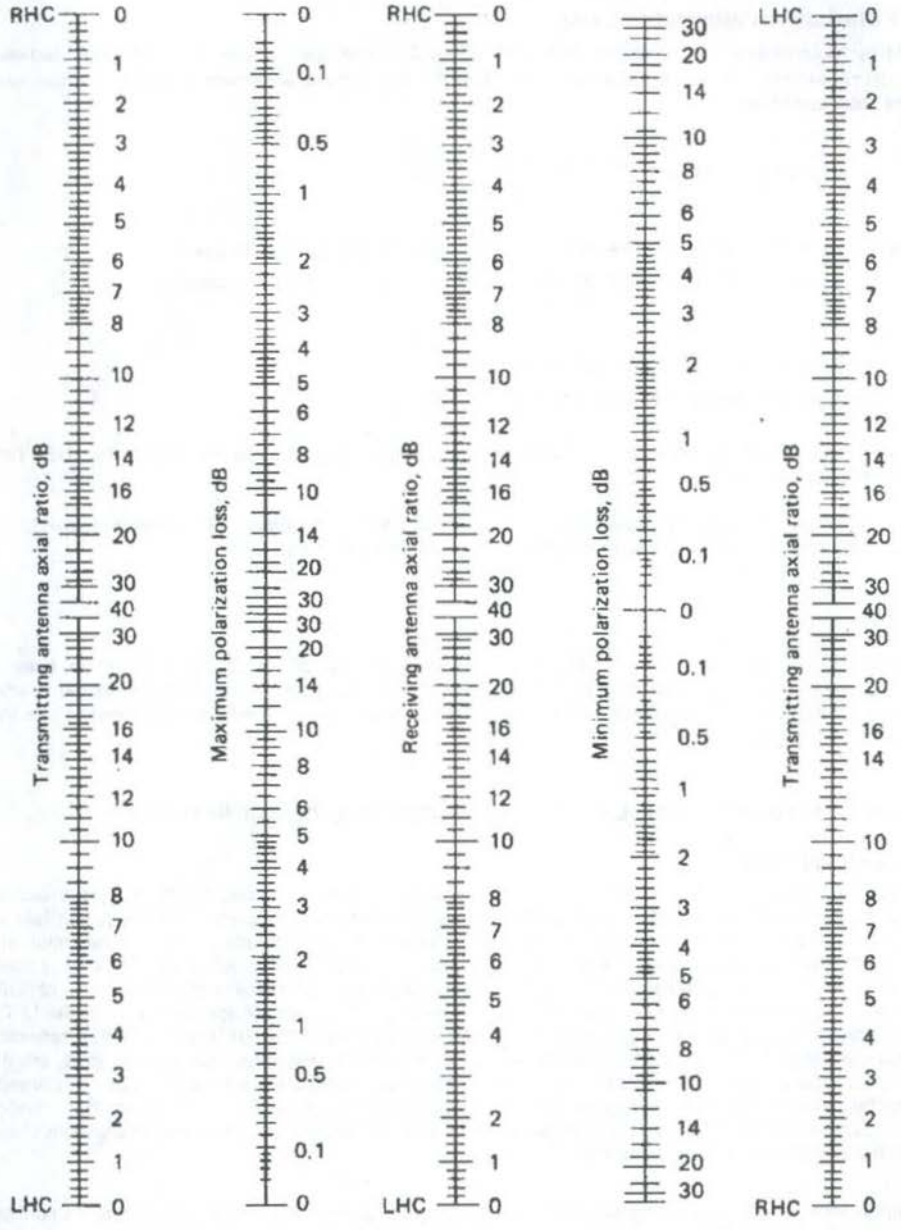


**Fig. 1 Maximum and minium polarization loss (reprinted from [2]., with John Wiley & Sons, Ltd., permission)**

**Abb. 1 Maximaler und minimaler Polasisationsverlust (entnommen aus [2] mit Genehmigung von Wiley & Sons, Ltd.)**

## 1.2 Polarization Mismatch Loss

For linear polarization, the mismatch loss is given by $\Gamma = \cos^2(\theta)$, where $\theta$ is the angle between polarization vectors. The polarization mismatch loss for any angular alignment $\theta$ between major axes can be calculated from (4):

$$\Gamma(\text{dB}) = 10 \log \left[ \frac{1+\rho_w^2\rho_A^2 + 2\rho_w\rho_A \cos 2\theta}{(1+\rho_w^2)(1+\rho_A^2)} \right] \qquad (4)$$

where $\rho_w = (r_w+1)(r_w-1)$ = the circular polarization ratio of the transmitted wave

$\rho_A = (r_A+1)(r_A-1)$ = the circular polarization ratio of the receiving antenna

and $r_w$ = axial ratio of transmitted wave (not in dB)

$r_A$ = axial ratio of receiving antenna (not in dB).

Note that the axial ratio is negative for RHEP (right-hand elliptically polarized) and positive for LHEP (left-hand elliptically polarized).

Since the actual calculation is somewhat impractical, various nomographs have been published. A nomograph showing maximum and minimum losses [2] is reprinted in Fig. 1.

Example 1

Consider the transmission between a RHEP TX antenna with axial ratio 6 dB and a RHEP RX antenna with axial ratio 2 dB. As read from the nomograph, the polarization mismatch loss is in the interval between 0.2 and 0.85 dB depending on the angle between major axes. This is not the dramatic loss that we might first imagine.

## 1.3 CP Crosspolarization Losses of a Parabolic Reflector Antenna

### 1.3.1 An Ideal Feed

Consider an "ideal" feed having RHCP (right-hand circular polarization) and LHCP (left-hand circular polarization) capabilities. "Ideal" means that the feed has symmetrical properties and each port has an axial ratio of 0 dB, so each port responds only to signals with the appropriate sense of polarization and signals with the opposite sense are infinitely attenuated. The feed is mounted at the dish's focal point. Now consider the antenna assembly of Fig. 2 receiving a purely RHCP signal with an axial ratio of 0 dB. Since the dish reverses polarization, the reflected signal is LHCP which will appear mainly at the LHCP port connector and will be very highly (but not infinitely) attenuated at the RHCP port. Perfect reflection with concurrent perfect transformation of the sense of circularity is only attainable with an ideal, infinite, conductive plane. Since the dish surface has parabolic curvature and finite size, a parasitic crosspolarization component having the opposite polarization is created in addition to the intended copolarization radiation. This means, that some degradation of the signal's axial ratio due to dish shape and diffractive effects must be taken into account.

Remarks: Incident CP electromagnetic fields induce a circular current on the parabolic reflector's surface, so to achieve proper reflection it is very important that the reflector has good omnidirectional conductivity and is preferably made of a solid material. Reflectors fabricated with rods or rough mesh are not suitable. Since the crosspolarization components are radiated at the expense of desirable radiation, their presence degrades the antenna's efficiency by a corresponding amount. For illustration, Fig. 3 depicts 2D radiation patterns of co- and crosspolarized components for 1296 MHz and a 3 m diameter dish with f/D=0.26 and 0.5 ratio. The feed is modeled with RHCP $\cos^N \theta$ illumination having a –10 dB edge taper. These types of polarization losses, originating in this case due to the parabolic reflector, are all considered to be **crosspolarization losses.**

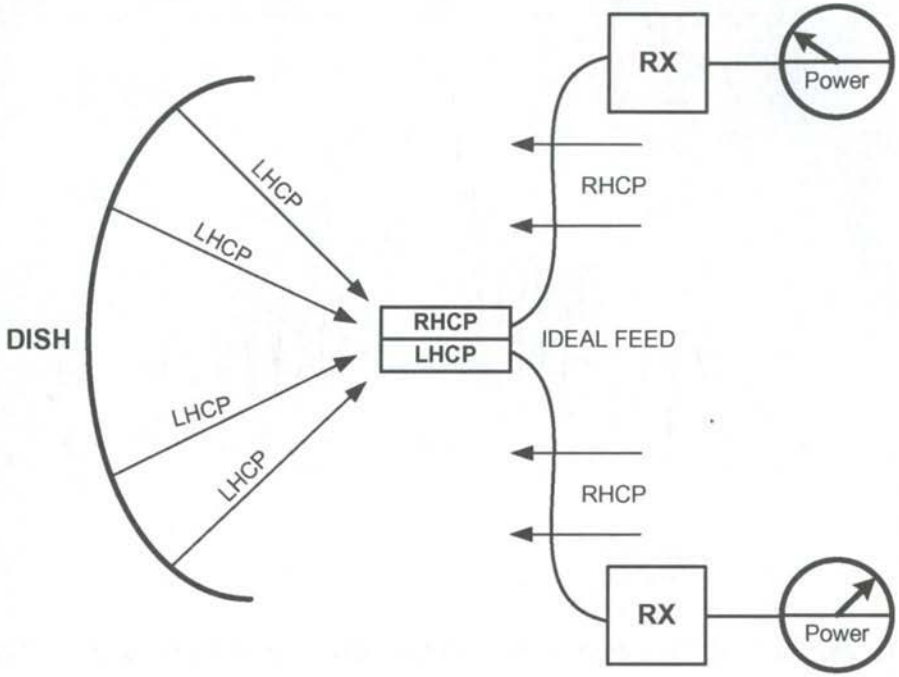


**Fig. 2**

Crosspolarization efficiency, in addition to illumination, spillover and phase efficiency (5), is one of the four main independent components which lower parabolic reflector antenna performance [2]. From the diagram of Fig.3, it is evident that the crosspolarization component originating due to dish reflection is rather low and its amplitude depends on the f/D parabolic dish ratio. It has continuous proportion; a deeper dish has a larger crosspolarization component. Since the amount of crosspolarization losses created by a parabolic reflector is about 40 dB, additional efficiency calculations may be neglected. This has been demonstrated using ICARA [3] software.

### 1.3.2 A Real Feed

Waveguide feeds that produce circular polarization generally consist of three interfuse sections:

A. Waveguide excitation section - coaxial to waveguide transition
B. Polarization transformer
C. Radiation section

Real feeds designed to deliver a specific sense of CP radiation will also radiate a crosspolarized component. The amount of energy radiated in this undesirable component primarily depends on the quality of the feed's integral polarization transformer. Another source of the crosspolarized component arises from the radiation section due to unbalanced surface currents originating on the open side of the waveguide. An electromagnetic field excited by these currents is radiated mainly in the reverse direction. State-of-the-art software permits determination of both of these components, so the antenna performance analyses are fairly accurate. To illustrate some of the software's capabilities, Fig. 7a, 7b and 7c show the computed copolarization and crosspolarization patterns and the axial ratio for a feed with square cross section equipped with a 4-step septum polarizer.

The feed's polarization efficiency has been evaluated using the following equation (consider the LHC port as being active):

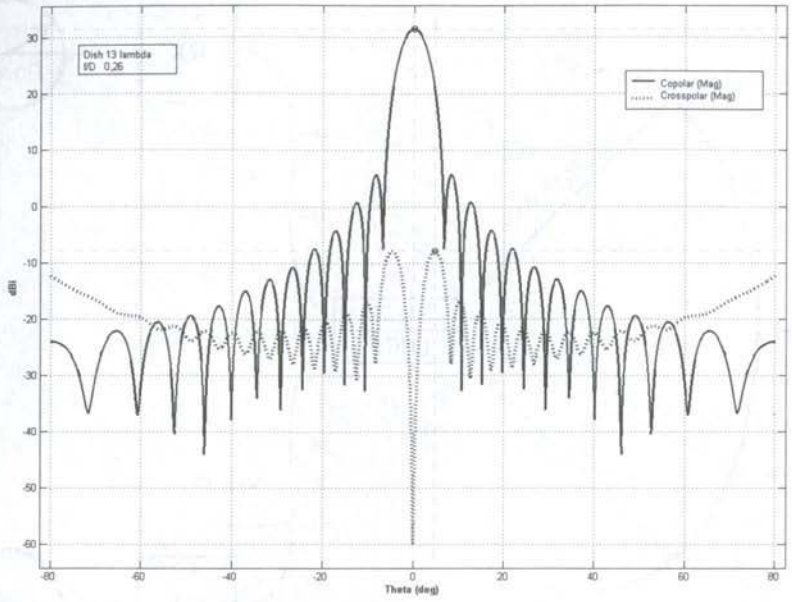


**Fig. 3a: Far field: Phi constant cuts MAGNITUDE – Dish 13 lambda, f/D 0.26**

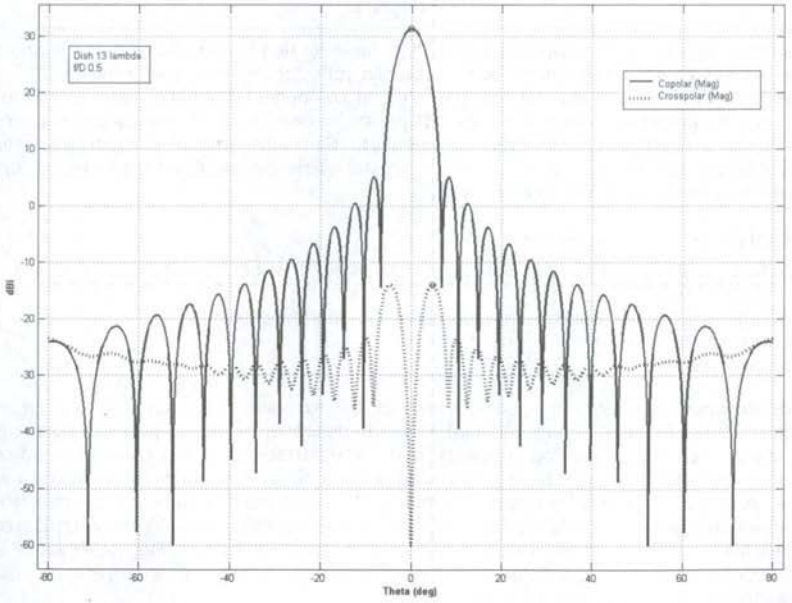


**Fig. 3b: Far field: Phi constant cuts MAGNITUDE – Dish 13 lambda, f/D 0.5**

$$\eta_{POL} = \frac{P_{LHC}}{P_{LHC} + P_{RHC}}, \qquad (6)$$

where $P$ is radiated power calculated by integrating the feed's farfield pattern over the sphere.

For further illustration, Tab. 1 lists calculated polarization efficiencies for various feeds. Calculations were performed by CST Microwave Studio [4] and MATLAB [5] software. Pure CP excitation of feeds was modeled by two simultaneously excited orthogonal modes with 90° phase shift. Data in the table suggest that polarization efficiency is affected by the presence of a choke and its position, in addition to the polarization transformer. Since crosspolarization losses are not very high, some recently published antenna analyses ignore them [6]. Regardless, determination of accurate antenna efficiency requires that these analyses be taken into account, especially when the choke position is more than 0.2λ back from the open end of the waveguide. Additionally, to achieve good parabolic antenna efficiency, not only polarization efficiency but all other factors (5) must be taken into account.

| Feed Style | Waveguide Diameter λ | Choke Dimension Width x Depth λ | Choke Position X λ | Efficiency % |
|---|---|---|---|---|
| Round Waveguide | 0,8 | | | 97,7 |
| Round Waveguide | 0,71 | | | 96,1 |
| Square Feed | 0,63 x 0,63 | | | 96 |
| VE4MA | 0,8 | 0,5 x 0,5 | 0,15 | 97,1 |
| Super VE4MA | 0,8 | 0,61 x 0,46 | 0,15 | 99,2 |
| Chaparral 1 Ring | 0,8 | 0,25 x 0,32 | Flush | 99,9 |
| Chaparral 3 Rings | 0,8 | 0,24 x 0,32 | Flush | 99,9 |
| Chaparral 3 Rings | 0,8 | 0,24 x 0,32 | 0,15 | 99,3 |
| Chaparral 3 Rings | 0,8 | 0,24 x 0,32 | 0,3 | 98,4 |

**Table 1 – Feed Polarization Efficiency / Tab. 1 Feed-Polarisationseffektivität**

## 2. Performance of a Parabolic Dish Antenna for CP

To gain a better understanding of polarization losses, the polarization characteristics of a parabolic dish antenna with 0.4 f/D ratio and 20λ diameter were calculated. The dish was illuminated by a VE4MA style feed. A choke with dimensions 0.5 x 0.5λ was positioned 0.15λ back from the waveguide's open end. See Fig. 4. The feed was excited by two identical signals with 0 to 90 degrees phase difference in 15 degrees steps. In practice it is quite simple to realize this phase difference by varying the coaxial line lengths between the hybrid power divider and feed to verify the computer simulation.

Computer simulation was used to calculate antenna performance. The feed was modeled using CST Microwave Studio [4] and FEKO software [7] was used to calculate parabolic dish antenna performance as regards axial ratio, co- and cross-polarization directivity and total directivity. Respective characteristics are shown in Fig. 5. Detailed analysis of each computed parameter follows:

### 2.1 Axial ratio

From the graph of Fig. 5, it is evident that phase differences between the excitation signals cause changes in the axial ratio. The more the phase shift differs from 90 degrees on either side, the more the axial ratio deteriorates. The graph shows a very small difference between the feed axial ratio and the antenna axial ratio for boresight transmission. This validates the simulation described in the previous section. Variations in axial ratio due to reflection from the parabolic dish are minor and may be neglected. A properly designed feed should have a low axial ratio within the feed subtended angle for the respective

dish ratio f/D. In EME communication, the axial ratio of the reflected signal is influenced by the Moon's rough and inhomogeneous surface, by Faraday's rotation, the station's position on the Earth, etc. These factors degrade the signal even if a perfect CP signal (axial ratio=0 dB) has been transmitted and the received CP signal exhibits statistical behavior consistent with its axial ratio.

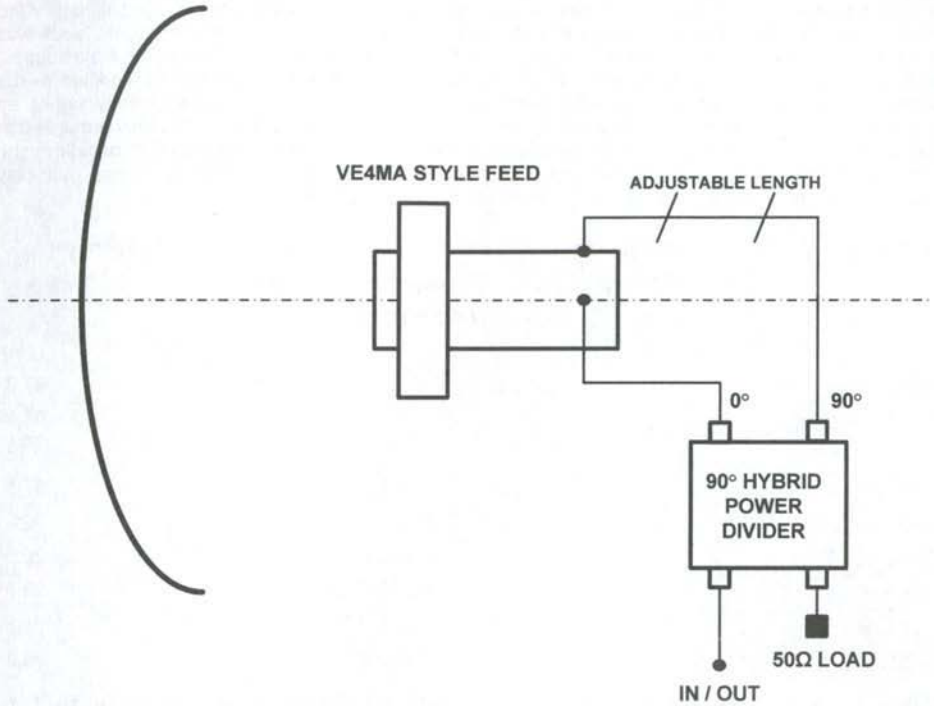


Fig. 4

## 2.2 Co-polarization directivity

The co-polarization directivity value depends on the uniformity of circular polarization. When the phase shift equals 90 degrees, the axial ratio approaches 0 dB. 0 dB can be achieved in an antenna assembly having no crosspolarization losses when co-polarization directivity is identical with the total directivity. In other words, the antenna operates at its highest possible efficiency when receiving a pure CP signal with the same sense of polarization that the antenna is designed to receive. When the phase shift equals 0 degrees, linear polarization is produced instead of CP and co-polarization directivity falls to a minimum, which is 3 dB below the total directivity for ideal linear polarization.

## 2.3 Cross-polarization directivity

Cross-polarization directivity represents the undesirable parasitic component. Similar to co-polarization, cross-polarization can be only as high as 3 dB below the total directivity when ideal linear polarization is provided. Alternatively, the more that cross-polarization is suppressed, the better the axial ratio will become.

## 2.4 Total/absolute directivity

The total directivity, which is also referred to as absolute directivity, denotes the directivity of signals having identical axial ratios and angles between both polarization vectors. As shown in the graph, the total directivity does not depend on phase shift between the excitation signals or the axial ratio and is

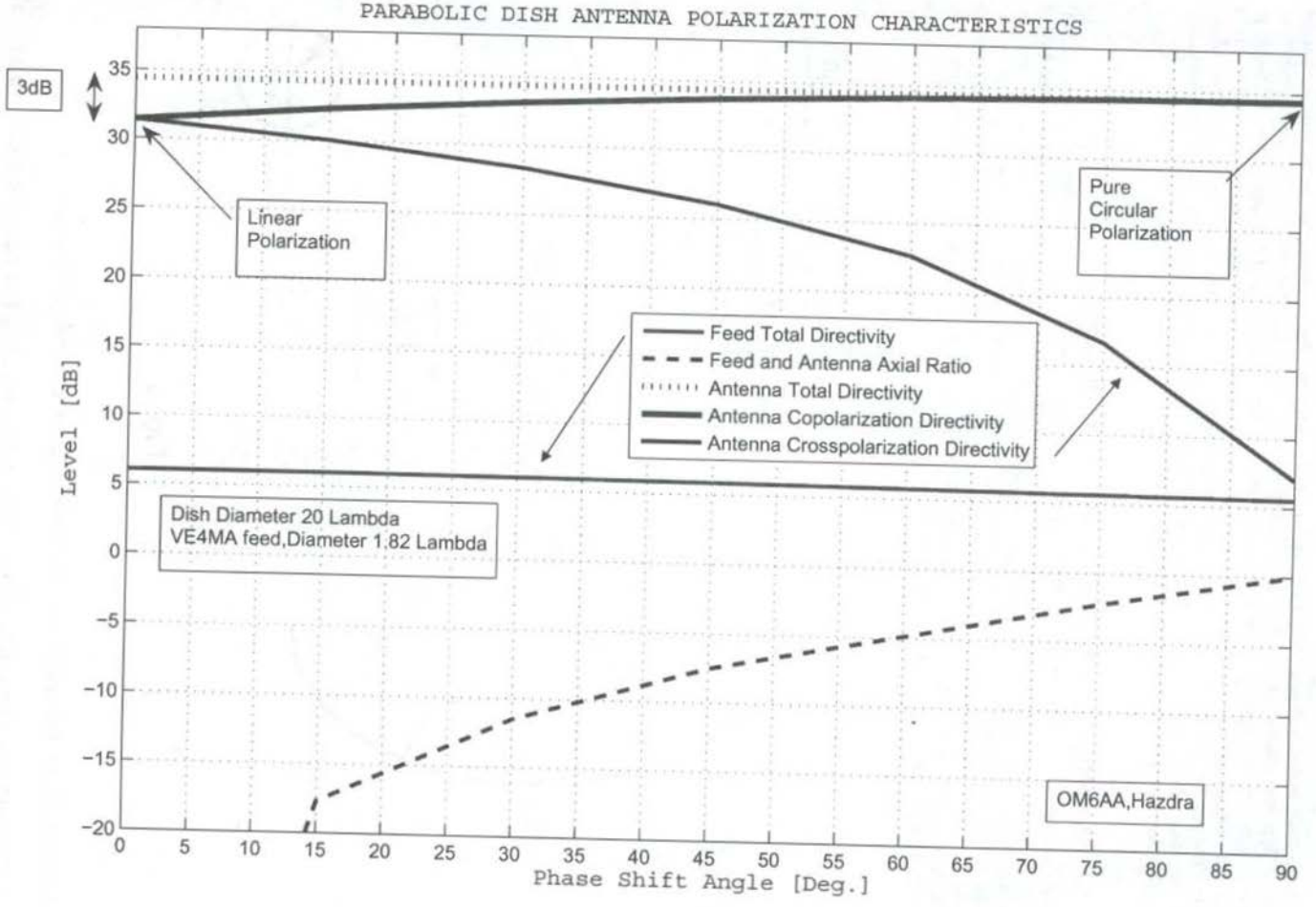
PARABOLIC DISH ANTENNA POLARIZATION CHARACTERISTICS
3dB
Linear Polarization
Pure Circular Polarization
Feed Total Directivity
Feed and Antenna Axial Ratio
Antenna Total Directivity
Antenna Copolarization Directivity
Antenna Crosspolarization Directivity
Dish Diameter 20 Lambda
VE4MA feed,Diameter 1.82 Lambda
OM6AA,Hazdra
Level [dB]
Phase Shift Angle [Deg.]
35
30
25
20
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90

Fig. 5

constant over its entire range. However, when we try to utilize total directivity for an antenna with axial ratio of 3dB and without any additional polarization mismatch losses, for example, such antenna must receive a compatible signal, i.e. the signal must have the same axial ratio of 3dB and alignment angle $\theta$ between polarization vectors. Such a situation may exist in EME communication for a short time, but for a longer period, the alignment angle $\theta$ will suffer from random variations due to Faraday`s rotation, Moon libration and others factors. As a result, polarization mismatch loss is created. Its behavior is statistical and its value can be estimated from the diagram in Fig. 1.

## 3. CP Parabolic Antenna and Sun Noise Optimization

When receiving sun noise with the described antenna assembly, the total directivity will be employed since sun noise is incoherent, that is, non-correlated. In this case the antenna adds noise power randomly from both co- and cross-polarization components since sun noise is not polarized. This may be easy verified by the measurement depicted in Fig. 6. If the feed has symmetrical properties, then the level of sun noise power on LHCP and RHCP ports is equal. As described above, total directivity does not depend on the polarization properties of an antenna, so its polarization parameters cannot be optimized by maximizing sun noise reception.

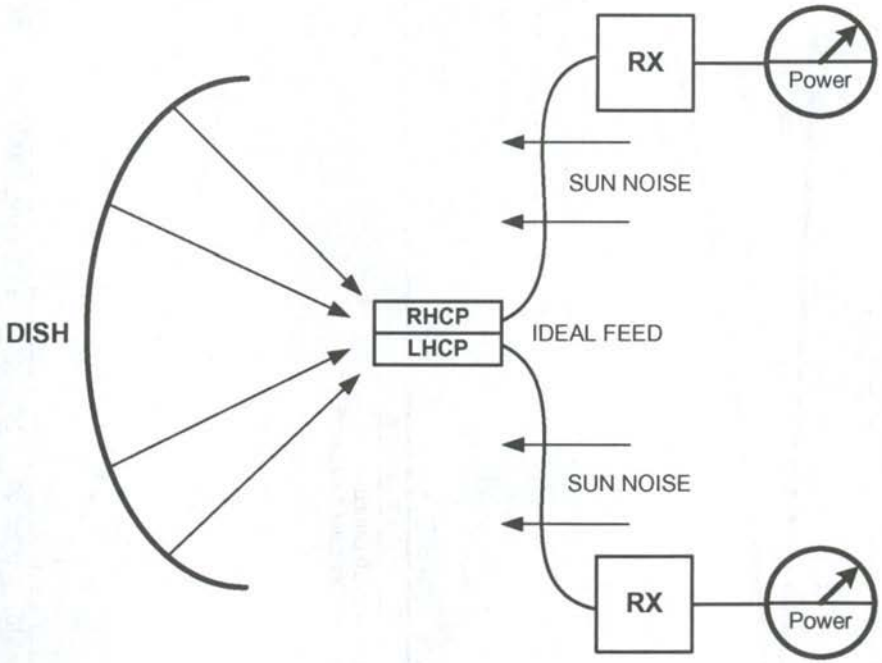


**Fig. 6**

Noting the polarization losses described above, we state the following conclusion:

**A CP antenna assembly optimized by maximizing the received sun noise/cold sky ratio is not optimized for the best circular polarization performance.**

## 4. Summary and Conclusion

It has been demonstrated that the operation and performance of circular polarization dish antennas differ significantly from that of antennas designed for linear polarization. Only with proper understanding of these differences is it possible to configure these antennas to attain optimum performance. This is especially true for small size CP antennas, where a reserve in gain is usually lacking.

Noteworthy is the fact that it is not possible to use sun noise measurements to investigate the polarization properties of parabolic dish antenna assemblies, while other antenna properties such as illumination and spillover efficiency may be properly optimized utilizing sun noise reception. Also, it is very difficult to adjust an antenna feed for proper CP performance without the use of special equipment since an inspection of the polarization pattern is required.

Consequently, when the verified design of a CP feed is copied, good polarization parameters are inherently attainable. Such design of a feed for 10 GHz was recently published [1, 8]. A CP feed for 23 and 13 cm utilizing a septum polarizer configured in a circular waveguide will be described in a future issue of DUBUS magazine.

## 5. Acknowledgement

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## 6. References

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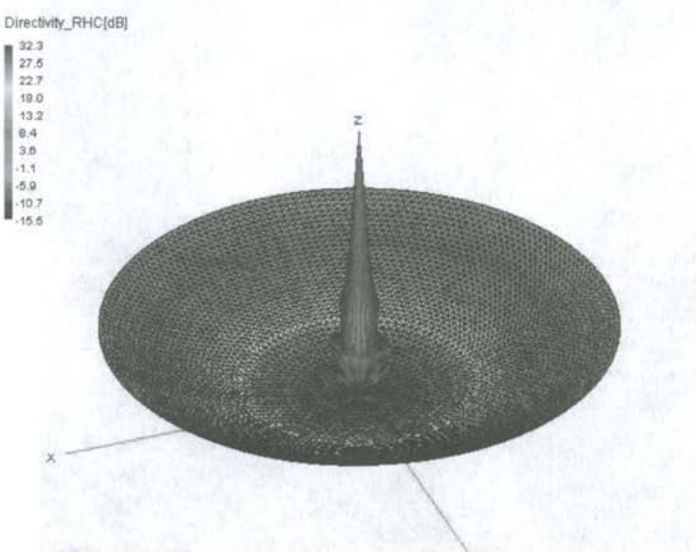


**Fig. 7 a Copolarization – see also cover for color picture**

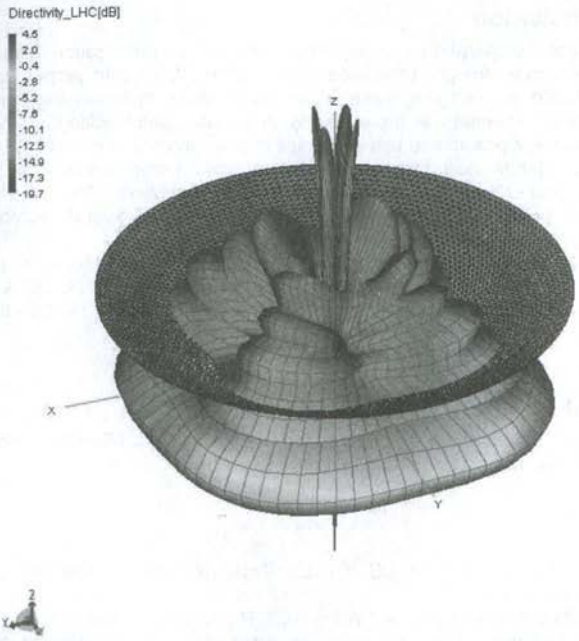


**Fig. 7 b Crosspolarization – see also cover for color picture**

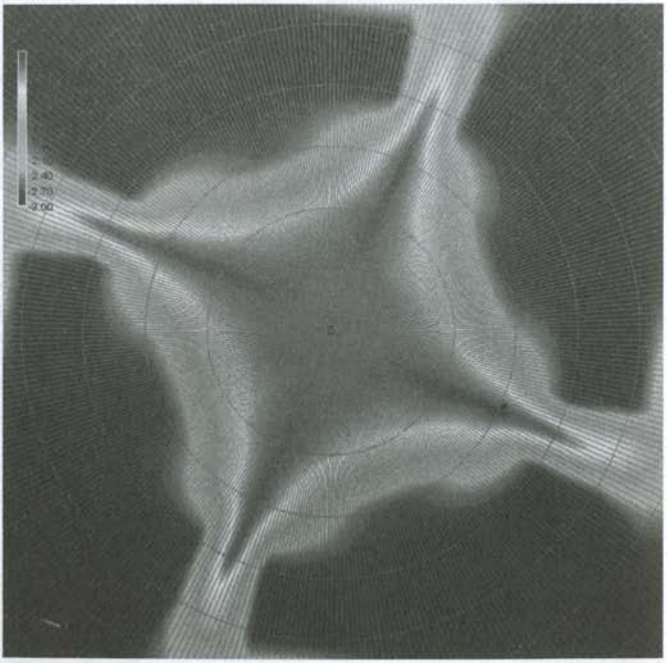

**Fig. 7c Axial ratio - see also cover for color picture**